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Service coverage factors affecting bus transit system availability

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Abstract

Over the last few years, transportation policies have aimed to shift transport demand from private car to transit systems. To achieve this objective, supplied transit services must be available to as many users as possible. Access to transit stops is an important factor. This research focuses on defining the service coverage area of a transit service, which is the area within walking distance of a transit stop, using a methodology suggested by the Transportation Research Board. The aim of this research is to calculate service coverage area for a transit system operating in the urban area of an Italian city. The results showed that street connectivity factor, grade factor and population factor have great influence on the determination of service coverage area, whereas pedestrian crossing factor does not impact service coverage area. However, grade factor was calibrated for American cities and does not fit the case of European and Italian cities, which have different topographical characteristics.

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Keywords: Transit service; System availability; Service coverage.

1. Introduction

The configuration of urban areas can be conceived as the result of interactions between the transportation and planning system (land use), which are mutually interconnected. The term “land use” is related to the variety of human activities which are held in the urban space. Land use and transport interaction is a dynamic process involving changes over spatial and temporal dimensions between the two systems. Changes in land use system can modify the travel demand patterns and induce changes in transportation systems. On the other hand, transportation system evolution creates new accessibility levels encouraging changes in land use patterns. The relationship between land use and transportation system in an urban area can be described through some spatial

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variables regarding geographical features and activity location, demographic and economic characteristics, transportation variables, and characteristics of the mobility demand (Eboli et al., 2012).

Over the last decade, travel behaviour has become more complex because the traditional journeys, from home to places of work or study, have been replaced by trip chains. These new characteristics of demand have led to widespread use of the private car (Eboli & Mazzulla, 2012a). Therefore, in the last few years transportation policies have aimed to shift transport demand from private motorized vehicles to transit systems. Many studies showed that the transport mode choice could be affected by the neighbourhood pattern. In other words, there are some neighbourhood patterns encouraging the use of transit services. Specifically, recent studies have talking about some strategies such as more compact, pedestrian- and transit-oriented development to change the land use pattern oriented to the use of the private car. Experimentation has shown positive effects of these interventions in some cities. In fact, new development, such mixed-use environments, allows residents to utilize transit, walking, or bicycling for many of their trips, thus decreasing or at least not increasing congestion while creating a more liveable environment for everyone.

The reduction of the use of individual vehicles could resolve many problems, as reducing traffic congestion, air and noise pollution and energy consumption. To achieve this objective, supplied transit services must be available to as many users as possible. Particularly, being the first point of contact between passengers and service, access to transit stops is an important factor affecting overall transit use.

For estimating accessibility to transit service, particularly to transit stops, many aspects have to be considered. The Transit Capacity and Quality of Service Manual (TCQSM) (Transportation Research Board, 2003) presents transit service quality measures of transit availability and comfort and convenience for fixed-route service provided at transit stops, along route segments and corridors, and throughout a system. One of the main features of the TCQSM is its adoption of the level-of-service (LOS) concept introduced in the Highway Capacity Manual (HCM) (Transportation Research Board, 2000) for measuring transit service quality from users' perspectives.

Quantifying the quality of service of a transit system is much more complicated than evaluating a highway facility because of the involvement of multiple players (e.g., transit operators, passengers, vehicles) and a wide range of interrelated factors (e.g., spatial and temporal coverage, comfort level, reliability) (Eboli & Mazzulla, 2012b; Nocera, 2011). As a result, there are multiple LOS measures to evaluate the quality of service of a transit system or its specific components. Using multiple LOS measures involves some disadvantages as the difficulty to provide an overall quality-of-service evaluation required for comparing different transit routes, travel corridors, or transit systems (Fu & Xin, 2007).

According to TCQSM, transit stops availability was measured in terms of average headway, which is the inverse of the average service frequency. A current definition of service frequency is how many times an hour a user has access to the transit mode, assuming that transit service is provided within acceptable walking distance and at the user wished times. TCQSM defined route segments and corridors availability in terms of hours of service, which measures the number of hours during the day when transit service is provided along a route, a segment of a route, or between two locations.

System availability was explained in terms of service coverage, which measures the area within walking distance of transit service. Coverage exists if transit service is provided at the transit stop level. There are several types of service coverage measures. In general, service coverage LOS looks at how much of the area likely to produce users is served.

The aim of this research is to calculate the service coverage area for a transit system operating in the urban area of a medium-sized Italian city using the TCQSM methodology, to suggest any additional factor or modification to improve the methodology, and to adapt the values of the factors to the Italian case study.

The paper is organized as follows. In the next section a brief review of studies regarding public transit accessibility measures is presented. In Section 3 the TCQSM methodology for defining service coverage area is described. Section 4 presents the description of the case study and the performed analysis. Finally, concluding remarks are contained in section 5.

2. Public transit accessibility measures: a literature review

Measuring ease of access to transit services is important in evaluating existing services, predicting travel demand, allocating transportation investments, and making decisions on land development.

In the literature, transit accessibility is considered to have three primary components: trip coverage, spatial coverage, and temporal coverage (Mamun & Lownes, 2011).

Trip coverage means that travellers would consider public transit as accessible when it is available to and from their trip origins/destinations. Spatial coverage refers to transit accessibility if service is available within reasonable physical proximity to travellers home/destination. According to temporal coverage, a service is accessible when it is available at times that one wants to travel. Another key aspect of public transit service is comfort. Accordingly there is a need to assess and quantify public transit access considering the three aspects of public transit accessibility along with comfort.

Several studies have shown that the best methodology for measuring the quantity and quality of service should incorporate the three important categories of accessibility measures. However, in many cases it is not always possible to consider all these aspects.

Some of the existing measures of transit accessibility considered both spatial and temporal coverage. Among these, Ryus et al. (2000) developed the transit level-of-service (TLOS) indicator, which provides an accessibility measure founded on the existence of pedestrian route connected to stops. This indicator also combines population and job density with different spatial and temporal features to measure transit accessibility, and considers the level of safety of pedestrian route to stops.

The Time-of-Day-Based Transit Accessibility Analysis Tool developed by Polzin et al. (2002) considers both spatial and temporal coverage at trip ends. In addition, this tool incorporates the travel demand time-of-day distribution on an hourly basis considering the demand side of temporal coverage. The considered travel demand distribution is, however, limited to temporal fluctuation along the transit route and no spatial distribution is considered.

Other studies paid attention to the comfort and convenience aspect of transit service. Among these, Rood (1998) developed an index called Local Index of Transit Availability (LITA). This index measures the transit service intensity or transit accessibility in an area by integrating three aspects of transit service, as route coverage, frequency, and capacity. In other words, LITA is able to comprise spatial availability, temporal availability, and comfort and convenience at the same time.

As reported in the literature, urban processes and transportation issues are intrinsically spatial and space dependent. To find the processes of spatial distributions, it is necessary to manipulate a large amount of spatial data about urban areas using spatial analysis techniques. Over the last few years, the adoption of Geographic Information Systems (GIS) has supported urban analysis (Mazzulla & Forciniti, 2012). A GIS allows the spatial relationships among the variables to be studied, because it integrates common tasks performed on the database, such as statistical analysis, with the advantages of graphical representation of data and geographic analysis offered by maps. Using GIS it is possible to take advantages of representation of data by maps and spatial analysis of data from different sources.

In this regard, there are also many studies in which GIS was applied as a useful tool to contribute to transit accessibility definition. As reported in Foda and Osman (2010), pedestrian access to a bus stop is achieved through the pedestrian road network surrounding each stop, but previous research has not focused on the interaction bus stop locations and their surrounding pedestrian road network. Stop access coverage has been estimated using a circular buffer analysis with a radius of the access threshold around the transit stop in order to identify its coverage area. Knowing this area in addition to the population density, the total number of individuals in a region having suitable access can be determined. However, considering a simple circular buffer with a radius of the access threshold around each stop could cause an overestimation of the stop access coverage, because passengers could reach the bus stop from any location within the circular buffer. In their research, using the benefits of the GIS network analysis functions, the authors presented an approach for estimating transit stop access coverage based on the actual pedestrian road network surrounding the bus stop. In other words, all the pedestrian road network links that lie within the specified maximum walking distance of the 400 meters access threshold were identified and measured along the network paths around the bus stop. A polygonal area can be created joining the ends of those links. This polygonal area is considered more representative than a circular buffer for measuring the access coverage of a bus stop.

Other studies proposed applications of transit accessibility measures, as defined by TCQSM, to case studies with different features. For example, Jumsan et al. (2005) focused on the determination of transit service coverage which is one of the basic studies on fixed-route transit service availability in system. The presence or absence of transit service near one's origin and destination is a key factor in one's choice to use transit. When service is not available, other aspects of service quality do not matter for given trip. Transit service will be provided within a reasonable walking distance of one's origin and destination. However, TCQSM methodology only comprised topographical factors without considering user personal attributes. The authors suggested that for more practically determining bus service coverage area, passengers' attributes should be considered. The attributes affecting service coverage radius are residential area, gender, age, employed status, income per month, car ownership, frequency of week, and trip purpose. The paper presented not only the difference of marginal walking time by passengers attribute but also the derivation of the bus service determination model by passengers attribute. This model could be applied for estimating the number of passengers in certain spacing of bus stops despite of different demographic condition of the area.

Combining different measures of transit service accessibility, more comprehensive indices can be estimated. The objective of the paper proposed by Mamun and Lownes (2011) is to describe a method for quantifying public transit access combining existing public transit accessibility indices to harness the positive features of each. In particular, three methods (LITA, TCQSM, and the Time-of-the-Day Tool) were selected and applied to a case study individually and collectively. The results were compared and contrasted for consistency, completeness, and clarity. A composite accessibility measure was developed by integrating three methods. The results of a composite measure can be taken as a basis for adjusting the priorities of public transport services and addressing lack of services in public transport provision. This composite accessibility result, however, cannot reflect the changes in accessibility level for the micro-level changes in socio-economic and demographic characteristics of transit users.

3. Determination of service coverage area using TCQSM methodology

Service coverage is a measure of the area within walking distance of transit service. It is solely an area measure and it does not provide a complete assessment of transit availability. At the transit stop level, coverage exists if transit service is provided at that location.

TCQSM defined the area covered by a particular route as the air distance within 400 m of a bus stop or 800 m of a busway or rail station. This area can be performed drawing appropriately sized circles around transit stops by using GIS software. If accurate bus stop data are not available, this area can be approximated by outlining on a map all of the area within 400 m of a bus route. This approximation assumes reasonable bus stop spacing (at least four per kilometre). Sections of a route where pedestrian access from the area adjacent to the route is not possible (because of a barrier such as a wall, waterway, roadway, or railroad) should not be included in the service coverage area. However, this methodology does not embody any service coverage factors, as the effects of grades on walking distances, the proportion of older adults in the population, and the difficulty of crossing some streets. In addition, the number of people within walking distance is overestimated, because a lack of pedestrian connectivity could reduce an area's access to transit. Therefore, the TCQSM introduces four factors to correct each stop's service area: a street connectivity factor, a grade factor, a population factor, and a pedestrian crossing factor. In this way, each ideal transit stop's service radius is reduced in proportion to the weight of each factor. This can be expressed mathematically as shown in equation (1):

$$r = r_0 \cdot f_{sc} \cdot f_g \cdot f_{pop} \cdot f_{px} \tag{1}$$

where:
r = transit stop service radius (m);
r_0 = ideal transit stop service radius (m);
f_{sc} = street connectivity factor;
f_g = grade factor;
f_{pop} = population factor;
f_{px} = pedestrian crossing factor.

Street connectivity factor is a factor for reducing a stop's service coverage area in relation to the amount of out-of-direction travel a pedestrian is forced to make to get to a transit stop from the surrounding land uses. TCQSM defined three types of street patterns:

- a traditional grid system;
- an intermediate and hybrid layout;
- a cul-de-sac based street network with limited connectivity.

In the traditional grid street layout system, the streets are square to each other and there is very little out-of-direction walking required. Conversely, in a contemporary suburban neighbourhood there are limited entry points and dead-end streets. As a result, even if a transit stop is located not away in a straight line might be reached after more than a 15-minute walk away using the subdivision's street system. Obviously, a grid street pattern provides the most direct pedestrian access to transit stops. However, experimental studies showed that walking distances to and from a transit stop can still be longer than the corresponding air distance. TCQSM estimated street connectivity factors using the grid street pattern as the best case (table 1). The area type can be detected using the network connectivity index, defined as the number of links, as street segments between intersections, divided by the number of nodes or intersections in a roadway system.

Table 1. Street connectivity factors *(Source: Transit Capacity and Quality of Service Manual - 2nd Edition)*

Street Pattern Type	Network Connectivity Index	Street Connectivity Factor, f_{sc}
Type 1 – Grid	>1.55	1.00
Type 2 – Hybrid	1.30 – 1.55	0.85
Type 3 – Cul-de-Sac	<1.30	0.45

Grade plays an important influence on walking distance. In fact, the horizontal distance that pedestrians are able to travel in a given period of time decreases as the vertical distance climbed increases, particularly when the grade exceeds 5%. In this regard, TCQSM gives reduction factors for the effect of average grades on a given stop's service coverage area.

Table 2. Grade factor *(Source: Transit Capacity and Quality of Service Manual - 2nd Edition)*

Average Grade	Grade Factor, f_g
0-5%	1.00
6-8%	0.95
9-11%	0.80
12-15%	0.65

The breakdown of population by age affects pedestrian walking speed, which is highly dependent on the proportion of elderly pedestrians (65 years or older). In fact, the average walking speed of a younger adult is 1.2

m/s, but when elderly pedestrians constitute 20% or more of the pedestrian population, it becomes 1.0 m/s. For transit stops where 20% or more of the boarding volume consists of elderly pedestrians, a population factor, f_{pop}, of 0.85 should be used to account for the reduced distance travelled during a 5-minute walk.

Another factor that could be affect walking distance is the difficulty of crossing some streets. In particular, any crossing delay in excess of 30 seconds results in added travel time to reach a transit stop, in addition to the actual walking time. This causes a reduction of walking distance and a reduction in the size of a stop's service coverage area. A possible equation for the calculation of pedestrian crossing factor is:

$$f_{px} = \sqrt{\left(-0.0005 d_{ec}^{2} - 0.1157 d_{ec} + 100\right)/100} \tag{2}$$

where:
f_{px} = pedestrian crossing factor;
d_{ec} = pedestrian crossing delay exceeding 30 seconds (s).

Pedestrian crossing delay depends on crossing type. At signalised pedestrian crossings, average crossing delay is based on the cycle length and the amount of time available for pedestrians to begin crossing the street. At unsignalized pedestrian crossing where pedestrians do not have the right-of-way, average crossing delay is based on the crossing distance, average pedestrian walking speed, and traffic volumes.

After that the service coverage area is defined, it must be compared with the analysis zones data in order to estimate the number of people having the service as available, and to detect whether the supplied transit service suits the potential demand of travel. For this purpose, TCQSM methodology considers *transit-supportive areas* (TSA) as areas with a minimum density capable of supporting hourly service. A density of approximately 7.5 units per gross hectare is a typical minimum residential density for hourly transit service to be feasible, in which gross hectares are total land areas, which may include streets, parks, water features, and other land not used directly for residential or employment-related development.

TCQSM suggested that service coverage LOS depends by the ratio of service coverage area and transit-supportive area and regards the number of potential trip origins and destinations available to potential passengers (table 3).

Table 3. Fixed-route service coverage LOS *(Source: Transit Capacity and Quality of Service Manual - 2nd Edition)*

LOS	% TSA Covered	Comments
A	90.0-100.0%	Virtually all major origins and destinations served
B	80.0-89.9%	Most major origins and destination served
C	70.0-79.9%	About 3/4 of higher-density areas served
D	60.0-69.9%	About two-thirds of higher-density areas served
E	50.0-59.9%	At least 1/2 of higher-density areas served
F	<50.0%	Less than 1/2 of higher-density areas served

At LOS "A", 90% or more of the TSA has transit service; at LOS "F", less than half of the TSA has service. It does not give information about service quality and users satisfaction.

4. Case study

4.1. Description of the study area

The case study focuses on the urban area of Cosenza, which forms a single urban area together with Rende in the northerly direction. This urban area, placed in Calabria Region (South of Italy), is the most important centre of attraction for all the towns of the province because it performs some administrative functions and offers different services and job opportunities. Furthermore, Rende is home to the University of Calabria (UniCal), which affected mobility characteristics of all the urban centres of the province.

For providing a preliminary characterization of the urban area, it is necessary to report some information about population and economic activities (ISTAT, 2001a). Concerning population and housing, more than 70,000 people are resident in the city of Cosenza; on the other hand, the city of Rende has a resident population of about half of Cosenza population. It is necessary to specify that Cosenza and Rende feel the effects of the presence of the University of Calabria; so, in addition to the resident people there are other many people (university students) living in the urban area, and especially in the city of Rende. The population of the urban area is equally spread between males (48%) and females (52%). About 68% of the urban area population belongs to an intermediate class of age (between 15 and 65 years old), which represents the class of persons of working age; about 18% of people are older than 65 years and about 14% younger than 15 years. In the urban area there are about 40,000 families. A large part (about 26%) has one member; about 23% of families have two members; more than 40% are families with three or four components; finally, only 10% of families have five or more members.

The urban area fills up a surface area of about 82 km^2, and about 55% of the surface area is filled up by the city of Rende. By comparing population and surface area values of the two cities, Rende is larger than Cosenza, but it is less populated. This fact can be confirmed by observing the values of population density, which is the ratio of the population to the total size of the territory. The urban area offers about 47,000 housings, of which about 66% are in the city of Cosenza. By comparing the number of housings and surface area values of the two cities, Rende offers less housing than Cosenza.

Urban area labour force amounts to about 42,000 persons, of which about 66% of the city of Cosenza, and the remaining 34% of the city of Rende. In the urban area there are about 33,000 resident employed persons, and specifically about 22,000 in Cosenza (65%). Obviously, these percentages are correlated to the population size. In fact, in order to compare the employment data of the two analysed cities and to give more specific information about the levels of employment, some rates can be calculated. As an example, the regional employment rate gives an idea about the levels of employment by considering employed persons as a percentage of the population. In this study case, the employment rate is equal to 31% for the urban area, 29% for the city of Cosenza, and 34% for Rende; therefore, Rende has a major number of people employed compared to the total population than Cosenza. Analogously, the regional unemployment rate can be calculated, by considering unemployed persons as a percentage of the economically active population (labour force). The urban area presents an unemployment rate of about 21%, Cosenza of about 23%, while Rende has the lowest value, equal to 18%. By analysing the data about the employment by sector of the studied area, persons are mainly employed in the services. While in Cosenza most of people are employed in the sector of the public services, the enterprises located in Rende prevalently refer to the business activities (ISTAT, 2001b).

Concerning mobility and transport facilities, the analysed area represents one of the main junctions of the Calabria railways and road system. The A3 Salerno-Reggio Calabria motorway, the SS107 Paola-Crotone state road, and the n.19 and n.19bis state road cross the urban area. Furthermore, the urban area is crossed by the Sibari-Cosenza and Paola-Cosenza railways lines, which assure the rail link between the Tyrrhenian and Ionian rail director. Finally, in the urban area of Cosenza merged the regional railway lines to Catanzaro and Sila, which have a narrow gauge.

Public transit services in urban area are provided by two transit agencies, one based in Cosenza and the other in Rende. The first enterprise especially works in Cosenza area, but also supplies routes to connect the most central areas of the city with neighbouring municipalities, including Rende.

The agency based in Rende provides links among the several city neighbourhood and with the centre of Cosenza. Particularly, this agency supplies transit services between the University of Calabria and the others districts of the urban area.

In the entire urban area 263 bus stops were taken over. The majority of these are localised in Cosenza. The analysis of data relating to public transport routes showed that many routes have common parts. Even if services are provided by both the agencies, in these cases the bus stops overlap. In this research the transit services provided by the two agencies were treated as forming part of a single system without distinctions.

4.2. Application of TCQSM methodology

For evaluating the service coverage area for the case study, the four corrective indices suggested by TCQSM were estimated concerning the urban area Cosenza-Rende. The analysis was carried out considering census data.

The results showed that street connectivity factor, grade factor and population factor have relevant influence on the determination of service coverage area (figure 1). On the contrary, pedestrian crossing factor does not impact service coverage area, therefore this factor is equal to 1.

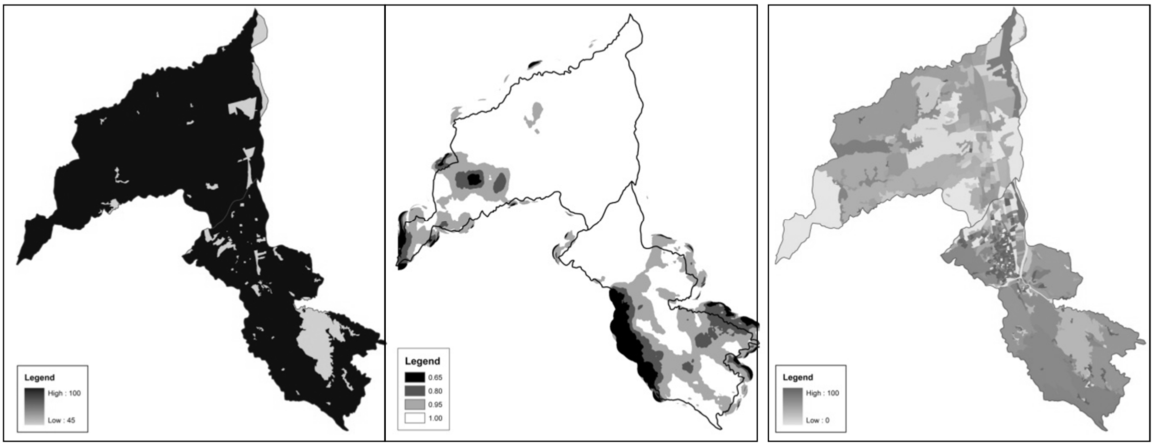

Fig. 1. Street connectivity factor (a), grade factor (b), population factor (c)

Using GIS, service coverage area was estimated. Knowing the rate of service coverage area for each census parcel, the average number of potential users of transit service can be determined. In the urban area, about 28% of the population is served by transit system.

After that the service coverage area was elaborated, transit-supportive areas were defined considering a density of approximately 7.5 units per gross hectare. In fact, the computation of TSA allows the definition of LOS, as the ratio of service coverage area and transit-supportive area. Figure 2 shows spatial distribution of bus stops in the urban area and the comparison between service coverage area and TSA. It is evident that service coverage area follows the distribution of TSA but it does not overlay the TSA along the entire urban area.

In the urban area Cosenza-Rende the percentage of TSA covered by service coverage area is about 32%, therefore service coverage LOS is “F” (table 3). This means that less than 1/2 of higher-density areas served by transit service. Even if transit service distribution along the urban area is not acceptable, LOS value is very low. A possible reason can be that the analysis was based only on census data. In this way, the analysis overlooked people living in the urban area but are not residents, as the university students. Hence, population factor gives a misinterpretation of the phenomenon, since it was elaborated on the basis of resident population that is older on average because it does not include younger population, as students. As a result, the analysis should be based on more specific surveys that take into account the non-residents.

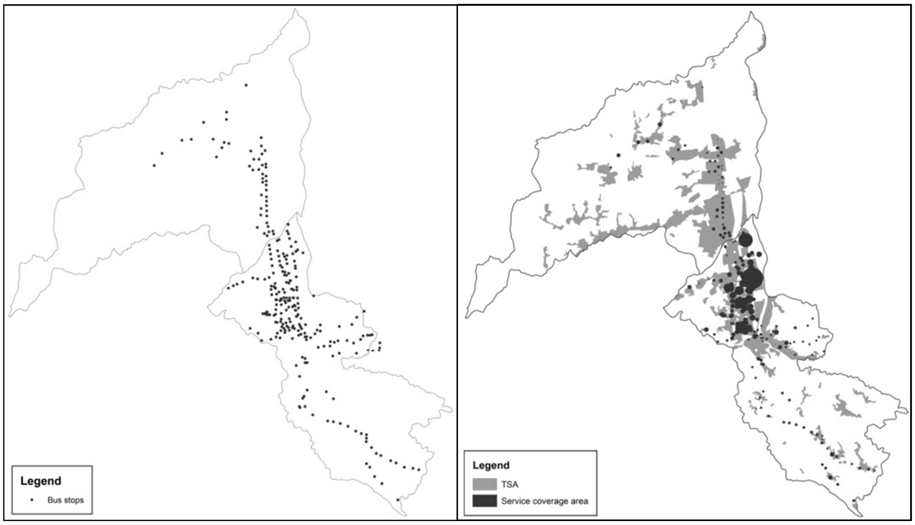

Fig. 2. Spatial distribution of bus stops in the urban area (a), and transit-supportive area compared with service area (b)

In addition, there are some gaps due to setting methodology. In fact, TCQSM methodology was defined using data from American cities which have different characteristics from European and Italian cities. In particular for the considered case study, grade factor heavily affects the decrease of each ideal transit stop's service radius of 400 meters. Italian cities have a different topography compared to American cities. In Italy the majority of the cities are hilly areas. For this reason, the population is accustomed to walking paths are not completely flat and the influence of slope on the walking speed is definitely lower than that considered in TCQSM methodology.

Table 4. Correct grade factor

Average Grade	Correct Grade Factor, f_g*
0-10%	1.00
10-12%	0.95
12-15%	0.80

A correct grade factor was suggested to adapt the methodology to the case study. The new ranges of average grade were calibrated on the base of the case study orography. Table 4 reports the new values of grade factor that were applied to evaluate service coverage LOS again. As a result of this modification, the percentage of TSA improved (52%) and LOS reached level "E", at which at least 1/2 of higher-density areas are served by transit service.

5. Conclusions

The aim of this research was to calculate the service coverage area for a transit system operating in the urban area of an Italian city of medium size using the TCQSM methodology. A useful tool for performing the analysis was GIS. A relevant step was the evaluation of the four factors to correct each stop's service area. In fact, this methodology accounts service coverage factors, as the effects of grades on walking distances, the proportion of older adults in the population, and the difficulty of crossing some streets. The results showed that street connectivity factor, grade factor and population factor have great influence on the determination of service coverage area, whereas data showed that pedestrian crossing factor does not impact service coverage area, therefore this factor is equal to 1.

Regarding the case study, the analysis presented two problems. The first concerns the database used which does not include inside information relating to the non-resident population who has actually lived in the urban area. The second issue concerns the weight of grade factor. TCQSM methodology suggests that walking distance decreases when the grade exceed 5%. This value was calibrated for American cities and does not fit the case of European and Italian cities, which have different topographical characteristics. As reported by de Oña et al. (2012), also in the case of Granada (Spain) grade factor mainly influenced the reduction of ideal transit stop's service radius of 400 meters. Afterwards service coverage LOS was calculated for the case study, which has the lowest value, equal to "F". Obviously, LOS definition was affected by the gaps identified in the processing methodology. Taking into account the average grade detected in the case study, grade factor values were adapted to the Italian cities case. Repeating the analysis, different results were obtained.

Future development of the research can provide for the introduction of other kinds of data regarding actual population living in the city and potential users of public transit system. Interesting results could be obtained by introducing new corrective factors appropriately sought through ad hoc designed surveys for the Italian cities.

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